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WEAPON SYSTEM OPTIMIZATION MODEL (SYSMOD) DEMONSTRATION USER'S MANUAL

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13. ABSTRACT (Maximum 200 words)

The objective of this research was to illustrate the Weapon System Optimization Model (SYSMOD) concept and to show how it could be applied during the Concept Exploration phase of weapon system acquisition. SYSMOD is an integrated system of existing and new manpower, personnel, and training models for use in the weapon system acquisition process. The SYSMOD model guides the user through the process of: (1) defining operation and support scenarios that will be used to simulate the maintenance of th proposed new weapon system; (2) running a simulation to determine whether the available manpower meets the imposed criteria for weapon system availability and cost; and, (3) conducting machine-to-machine, man-to-man tradeoffs that will drive subsequent simulations so that the user can determine a good, cost-effective mix of maintenance hardware and Manpower-Personnel-Training (MPT) resources. Using primarily notional weapon systems and Air Force Specialties (AFSs), the model demonstration helps explain the SYSMOD framework, helps users to elicit information needed to build the model and serves as an effective training tool to convey the concept, operation, and benefits of SYSMOD to potential users in the Air Force.

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PREFACE

This work was completed as part of Work Unit 77191927, Development of MPT Acquisition Tradeoff Methods. This report provides a user's manual for a demonstration model for the Weapon System Optimization Model (SYSMOD) concept for manpower, personnel, and training (MPT) resourcing and costing during the Concept Exploration phase of weapon system acquisition. Although notional, SYSMOD does provide a basis for much of the design work leading to the MPT in Acquisition Decision Support System (MPT DSS) project being accomplished under Work Unit 29220302.

1. INTRODUCTION

A demonstration version (Demo) of the Weapon System Optimization Model (SYSMOD) for Concept Exploration was built to illustrate the operation of the model proposed in the first SYSMOD effort. The Demo proved valuable in developing the conceptual framework and R&D plan by helping us visualize the interaction between the components or modules that will comprise SYSMOD. The Demo also helps explain the framework to users to elicit information needed to build the model. Moreover, the Demo may prove to be an effective training tool to convey the concept, operation, and benefits of SYSMOD to potential users in the Air Force.

1.1 OBJECTIVE

The objective of this interactive Demo is to illustrate the SYSMOD concept and to show how it will be applied during Concept Exploration. SYSMOD is an integrated system of existing and new manpower, personnel, and training models for use in the weapon system acquisition process. The screens in this Demo guide the user through the process of:

a. Defining operation and support scenarios that will be used to simulate the maintenance of the proposed new weapon system;

b. Running a simulation to determine whether the available manpower meets the imposed criteria for weapon system availability and cost; and,

c. Conducting machine-to-machine, man-to-machine, and man-to-man trade-offs that will drive subsequent simulations so that the user can determine a good, cost-effective mix of maintenance hardware and Manpower-Personnel-Training (MPT) resources.

For purposes of this demonstration we have simplified the level of weapon system complexity in favor of focusing on the SYSMOD methodology. For that reason the weapon systems and Air Force Specialties (AFSs) are primarily notional, although we tried to maintain some semblance of reality.

1.2 MENU HIERARCHY

The hierarchy in Figure 1 is provided as a roadmap to guide the user through the Demo. Each vertical bar represents a menu; branches continue to the right to show screens and menus nested behind each option on a menu. In Figure 1, BCS stands for Baseline Comparison System and MTBF stands for Mean Time Between Failures. To execute an option on any menu highlight the appropriate option and press the <Enter> key. To move around inside a form, use the arrow keys

and the <PgUp> and <PgDn> keys. To return to the previous menu or form, press the <Esc> key. To move down to a form which lies beneath another form in the menu tree, press the control key and simultaneously press the <PgDn> key (i.e. <Ctrl>PgDn). The bottom of each form contains information about which keys perform the various functions.

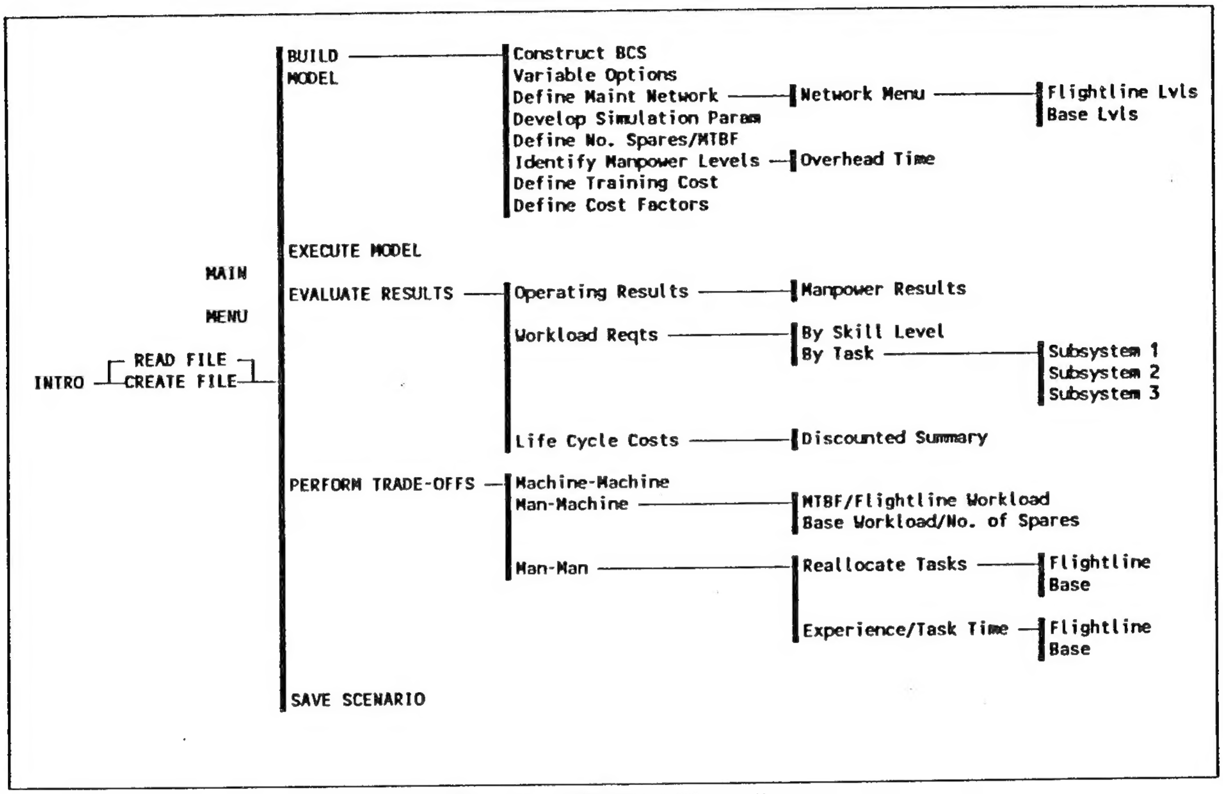

Figure 1. SYSMOD Menu Tree

2. USING THE DEMO

To activate the SYSMOD Demo and enter the main menu, the user should type "SYSMOD" and press the <Enter> key. Before entering the main menu, the user will view a SYSMOD logo followed by a screen explaining the purpose of the Demo. Press the <Ctrl> PgDn key to pass the logo screen, and press the <Esc> key to pass the explanation screen.

To load a previously saved simulation, select "Edit Existing Scenario" from the first menu. The Demo will prompt the user for a file to read. Press the <Insert> key to view a list of previously saved files. Once the user selects a file to load, the SYSMOD main menu will open. Selecting the "Create a New Scenario" option loads default data and starts the SYSMOD main menu. User generated scenarios are stored in DOS files with the extension ".smd."

2.1 MAIN MENU

The SYSMOD Demo main menu consists of five options: Build Model of Maintenance System, Execute Model, Evaluate Results, Perform Trade-off Analysis, and Save the Scenario to a File. Each of these five options is described in turn.

2.2 BUILD MODEL OF MAINTENANCE SYSTEM

When this option is selected, the Demo presents the user with a sub-menu of options. The purpose of this menu branch is to enter all of the input variables for the simulation. When creating a new scenario, the user should execute the options in the order they are presented. If the options are not selected in order, data input may be incomplete and the user may encounter error messages when running the model. To avoid incomplete data input, the model loads default data from the file db_data.asc upon selection of an existing weapon system in the Construct Baseline Comparison System branch. When creating a new scenario, the user should check every input screen. The color scheme of this menu branch is white and yellow on blue.

2.2.1 Construct Baseline Comparison System

The user is expected to enter the baseline or parent system for the three notional subsystems for the aircraft, namely Airframe: Subsystem One, Propulsion: Subsystem Two, and Communication, Navigation, and Identification Friend or Foe (COMM/NAV/IFF): Subsystem Three. When the user presses the <Enter> key on any of the three subsystem fields, a pop-up menu with two options appears. Each option allows the user to use as a baseline, data from an existing weapon system (in this case the F-15 or F-16 fighter aircraft). For the purposes of this Demo, we have used notional

data for each of these options. The user selects one of the options (either the F-15 or the F-16 fighter) to provide the Demo with the appropriate data. Note that a selection must be made for all of the subsystems or the Demo will not operate correctly. There is one screen on this menu branch.

2.2.2 Enter Variable Options

In this branch the user chooses units of measure for two inputs. First, select whether to conduct the analysis using grade or skill level as a measure of experience for flightline and base level maintainers. Second, select whether to conduct the analysis using sorties or flying hours. Sorties might be selected for analysis of a scenario involving short missions; while flying hours might be selected for analysis of a scenario involving long missions. There is only one screen on this menu branch.

2.2.3 Define Maintenance Network

This series of screens allows the user to define the maintenance network needed to service the weapon system under development. There are three levels of repair in this maintenance network. The first, the flightline level, represents the maintenance that is performed to remove and replace or to conduct a minor repair action. The second, the intermediate level, is located on the base and operated by the wing. A Line Replaceable Unit (LRU) from the subsystem in question is removed on the flightline and sent to the base or intermediate repair facility to be diagnosed and possibly repaired. The third level, the depot level, is a centralized repair location where Shop Replaceable Units (SRUs) or parts of the LRU are repaired or discarded. The user has the option to include base level maintenance for each subsystem in the model. When the user presses the <Enter> key on any of the three fields at the base level, he or she sees a pop-up menu with two options. By selecting "On", the user includes base-level repair for the appropriate subsystem. By selecting "Off", the user limits maintenance to that performed at the flightline level. The Demo requires maintenance on the flightline ("hard-coded in") and does not model maintenance at the depot level ("hard-coded out").

After selecting which subsystems will have base level maintenance, pressing <Ctrl>PgDn presents a sub-menu with options to examine the maintenance network in further detail. Selecting an item on the menu produces a screen with a schematic portrayal of the maintenance network. Figure 2 shows the screen for the flightline level maintenance network, while Figure 3 shows the screen for the base level maintenance network. The purpose of these screens is to assign the AFS (in the field labeled "AFS"), the number in the workcrew (in the field labeled "Number"), the amount of time required to perform the various tasks (in the field labeled "Time") and the probability that a particular item will follow one of the branches (in the field labeled "Prob").

To understand the flightline level maintenance network shown in Figure 2, consider that for each subsystem, when a malfunction occurs, that subsystem follows the path of the maintenance network in order to be repaired. The subsystem begins at the box titled "Subsystem Aircraft" and works its way through the network following the solid lines. In the example in Figure 2, the subsystem is analyzed by a team of three maintainers of notional AFS 1. (Also labeled AFS 458X2_X, this is the Air Force Specialty Code (AFSC) for an air frame repairer where the first X indicates an unspecified skill level and the second X indicates flightline). The time to task completion is 1.0 hours. At this point, the LRU enters one of the three branches. First, the LRU might be removed and replaced and sent to the intermediate repair level for further diagnosis (with a .5 probability). Second, the maintainers could find no problem with the LRU and declare the failure to be spurious labeling it "Cannot Duplicate" (with a .3 probability). Third, the LRU could be repaired on the flightline under "Minor Repair" (with a .2 probability). Finally, the LRU is tested on the aircraft in the "Verify Action" step.

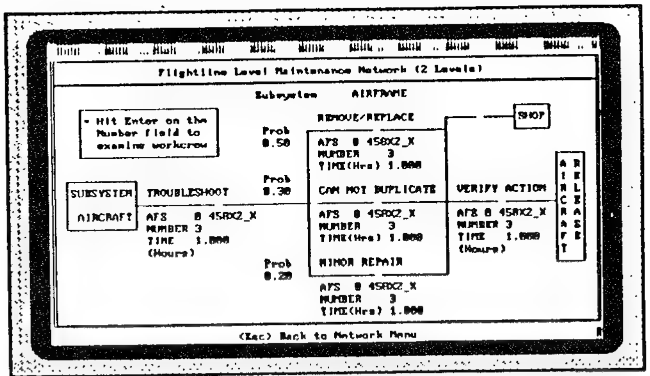

Figure 2. Flightline Maintenance Network

Figure 3 shows the maintenance network for base level repair. When an LRU is removed during flightline maintenance, it is sent to the intermediate level, the back shop or base level shop, for repair. A team of troubleshooters analyzes the LRU (in Figure 3, a mean time to repair of 7.0 hours) and determines either that it needs a major repair (with .4 probability in Figure 3) or that it cannot be fixed and sends it to salvage (with .6 probability).

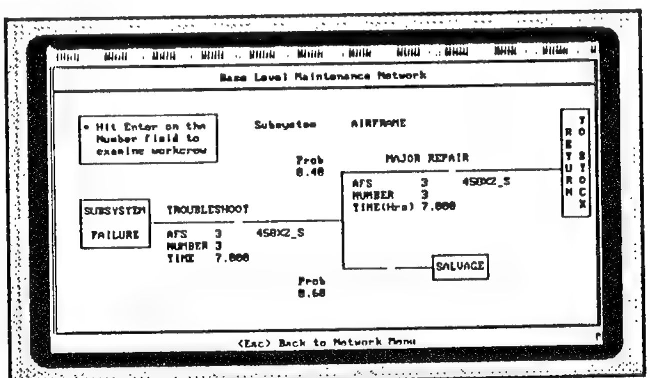

Figure 3. Base Level Maintenance Network

To define the workcrew in terms of training, experience and aptitude requirements, press the <Enter> key twice on the "Number" field. This brings up a screen outlining these elements and allows for changes. (Figure 4.) The screen allows for editing several variables. These include the skill level or grade of each member of the workcrew, the total weeks of training (classroom and Field

Training Detachment (FTD)), and aptitude of the maintainer required for the task.

Note that selecting a value in the AFS field (AFS=1,...,6) selects a notional code (AFSC) for the specialty, not the number of AFSs or people performing the task. The field for displaying the AFSC changes automatically when the user changes the value in the AFS field.

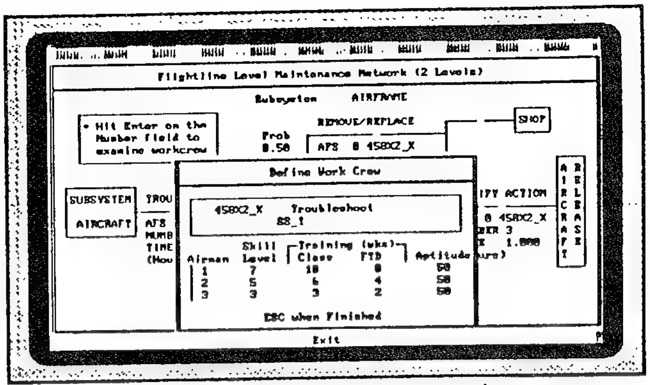

Figure 4. Workcrew Information

2.2.4 Develop Simulation Parameters

The screen entitled "Build Simulation Scenario" allows the user to define up to five types of missions that the aircraft will fly. (Figure 5.) The user should enter the number of missions required per day, the number of aircraft required to perform the mission, and the length (in hours) of the mission. The number of aircraft is hard-coded in at 72. There are two possible errors that the SYSMOD Demo ensures against. First, the user must enter values for at least one mission or the Demo will not allow the user to leave the screen and continue with the simulation. Second, if the user enters more missions than the wing can possibly support and tries to exit this screen, an error message will appear indicating that the user must correct the error before returning to the program. There is one screen on this menu branch.

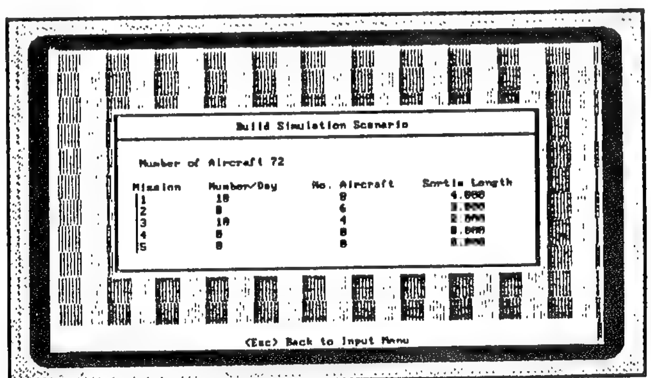

Figure 5. Build Simulation Scenario - Missions

2.2.5 Define Level of Spares

The screen entitled "Machine Supportability Factors" allows the user to define the monthly spares purchase (units are numbers of spare LRUs), the cost of one spare LRU (in thousands of dollars) and the Mean Time Between Failures (MTBF) (measured in numbers of sorties or flying hours) for each subsystem. (Figure 6.) This screen allows for changes to three parameters that

interact. Note that a certain number of spare LRUs must be purchased monthly to satisfy losses during the simulation. That is, in accordance with the defined maintenance network, a certain number of LRUs cannot be repaired and must be thrown away. Those that are thrown away must be replaced through the monthly LRU purchase, otherwise the simulation will show a loss of sortie generation potential. This process is explained in greater detail in Section 8 of the Appendix. By pressing <Enter> on the "Monthly Spares Purchase" fields, the user can see if the demand for spares on that particular subsystem is met. When the demand is not met, a warning message tells the user how many spares are required to avoid losing sorties. There is only one screen on this menu branch.

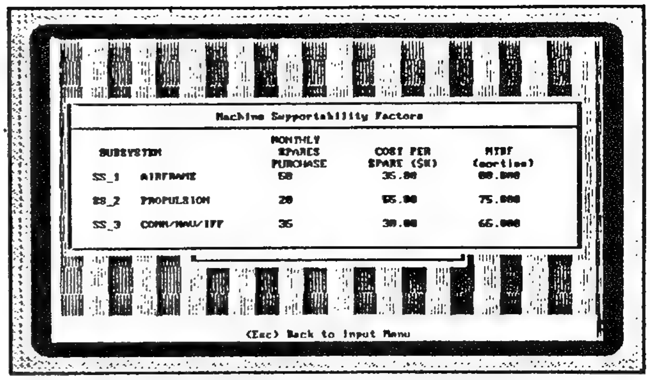

Figure 6. Machine Supportability Factors

2.2.6 Identify Manpower Levels

The screen entitled "Manpower Constraints" allows the user to enter the matrix of maintainers available to the simulation for each skill level of each notional AFS. The AFSs are listed vertically and experience levels are listed horizontally. Each field in the matrix corresponds to the number of maintainers available for the experience level at the top of the column and for the AFS at the far left of the row.

Pressing <Ctrl>PgDn allows the user to identify the percentage of time spent on overhead tasks for flightline and base-level maintenance. The default value of 22% is the same value typically used in the Logistics Composite Model (LCOM); however, this variable can be edited. Shift policy cannot be changed from its default value of three shifts per day.

2.2.7 Define Training Costs

This screen allows the user to define the training costs. Costs are defined in thousands of dollars per week. Training costs are entered for each experience level of each notional AFS (four experience levels and six notional AFSs for a total 24 data entry fields). The number of weeks required for training an AFS is a function of classroom and FTD skills required for the skill level or grade as defined in the maintenance networks. Further discussion of the methodology involved in generating the length of training can be found in Section 5 of the Appendix. There is only one screen on this menu branch.

2.2.8 Define Cost Factors

This screen allows the user to define the yearly wage costs. Wage costs are defined in thousands of dollars per year. Data are entered for each experience level of each notional AFS, as in Section 2.2.7 above. There is only one screen on this menu branch.

2.3 EXECUTE MODEL

Selecting this option runs the "simulation", which takes only a few seconds to finish. The word simulation is in quotes since the SYSMOD Demo is not actually a simulation but a compilation of several expected value formulas used to approximate the results of a simulation. Before running the model make sure you have completed the data entry process. If a scenario was loaded from an existing file with a complete data set, you can execute the simulation without going through the data entry process.

2.4 EVALUATE RESULTS

This menu allows the user to view and evaluate the results of the simulation. If the required system performance is not met, the user should provide more resources until it is met. The color scheme of this menu branch is white and yellow on red.

2.4.1 Operating Results

The screen entitled "Summary" allows the user to see whether the desired sortie rate can be achieved. (Figure 7.) If the simulation yields a constrained sortie rate that exceeds the desired sortie rate, then the maintenance resources input to the model are sufficient to perform the required maintenance. The numbers in the fields are the total number of sorties or flying hours (depending upon what the user selected on the input screens) to be flown by all the aircraft in the wing in one day. Differences between the constrained (i.e. simulated) and desired sortie rates suggest that resources can be reduced or increased; either has implications for the system's Life Cycle Costs (LCCs). A complete discussion of the expected value calculations used to derive the results in this screen is located in Section 1 of the Appendix.

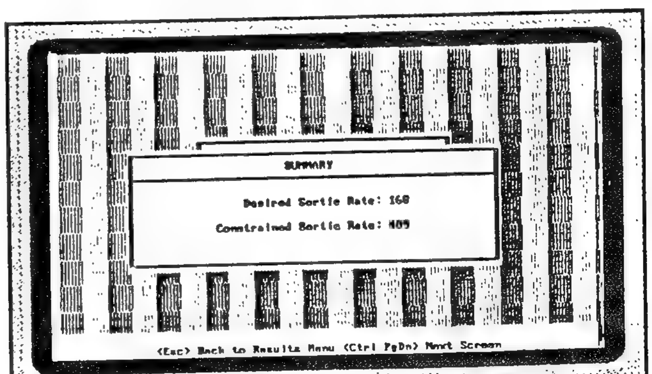

Figure 7. Sortie Generation Summary

Pressing <Ctrl>PgDn reveals the "Results" screen which compares manpower positions required with positions authorized. (Figure 8.) The column "Total Workload Requirements" shows the number of people in an AFS required to perform the assigned tasks. The column "No. of Positions Authorized" shows the number of positions of a particular AFS that were authorized by the user. The column entitled "Delta" shows shortages and overages.

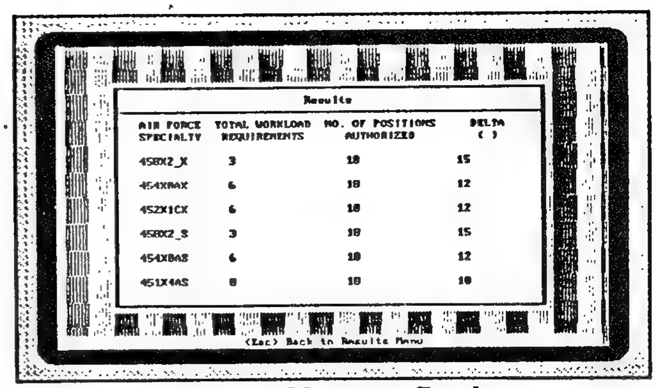

Figure 8. Manpower Results

2.4.2 Workload Requirements

The screen entitled "Simulation of Performance and Workload" shows the workload in terms of number of people required for each AFS. (Figure 9.) The workload for each AFS is computed using the algorithms outlined in Sections 2 and 3 of the Appendix. The number of Base Operating Support (BOS) people is estimated as a proportion of the number of maintainers, as explained in Section 4 of the Appendix.

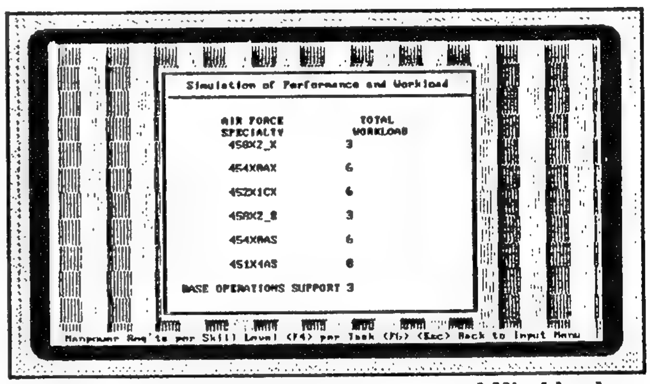

Figure 9. Simulation of Performance and Workload

By pressing <F4> the user can see a breakdown of the workload by skill level. These estimates are rounded up to estimate manning requirements. By pressing <F6> the user can see a breakdown of the workload by task for each subsystem.

2.4.3 Life Cycle Costs

The screen entitled "Life Cycle Cost Estimation" shows the total maintenance costs for manpower (both pay and training costs) and hardware incurred over the specified life cycle. (Figure 10.) The model includes inflation rates, which the user can enter or change if required. Enter the inflation rate in decimal form (i.e. enter 10% as 0.10).

Pressing <Ctrl>PgDn shows the form "Discounted Summary of Costs". (Figure 11.) This form displays the discounted present value of the LCCs computed for the simulation. The user should enter a discount rate (enter 10% as 10) and the projected system life cycle (in years).

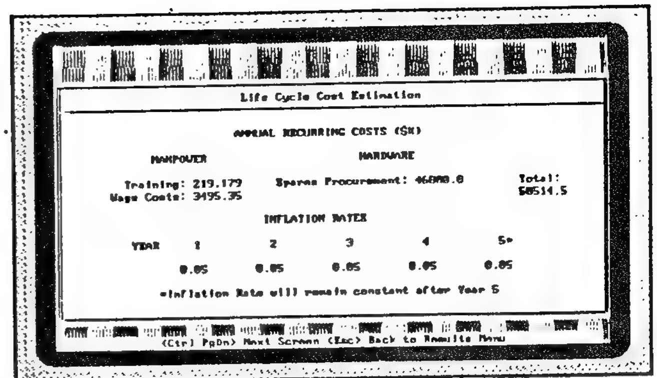

Figure 10. Life Cycle Costs

If the LCCs are too high, the user needs to access the trade-off section to design alternative resource combinations that will reduce LCCs. Once the new resource combinations are determined, the model inputs should be changed to reflect the new resources and the simulation must be rerun.

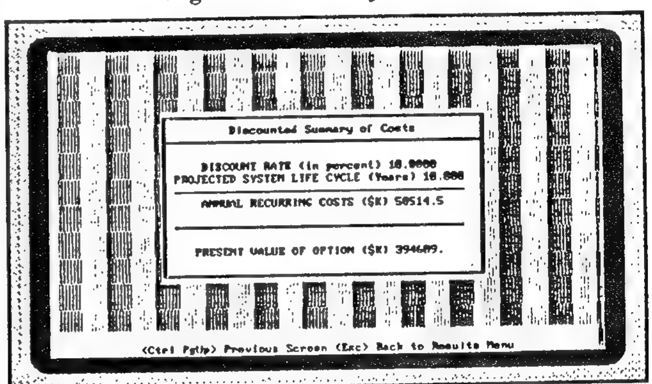

Figure 11. Discounted Cost Summary

2.5 PERFORM TRADE-OFF ANALYSIS

The trade-off section provides access to several models that allow the user to investigate effects of changes of one resource on maintenance performance and LCCs. Both hardware and MPT resource trade-off models are available. The trade-off models contain options to change simulation input and to rerun the simulation with the changes. Available trade-offs include performing trade-offs among hardware resources (machine-machine), between MPT resources and hardware (man-machine), and among MPT resources (man-man). The color scheme for this menu branch is white and yellow on black.

2.5.1 Machine - Machine Trade-Offs

Selecting this option allows the user to perform trade-offs among hardware resources. Figure 12 shows the SYSMOD Demo screen for this trade-off. The user can vary the MTBF and the cost of an individual spare. A proportional relationship between the two variables is assumed (i.e. an "X" percentage increase in the MTBF will cause an "X" percentage increase in the price of a spare) based on the hypothesis that MTBF can be increased with high technology, but high technology costs more than low technology. After changing any of the values in the MTBF fields, the user should press <F2> to see the resulting change in the cost of spares. Pressing <F4> will return the variables to

their original values (the values used in the latest simulation run). Pressing <F6> will re-run the model using the new values on this screen. By changing the value of the spares cost and pressing <F8>, the value of the spares cost will change without changing the value of the MTBF (but you will need to re-run the model by pressing <F6>). The <F8> key is useful if the user does not want to use the assumed proportional relationship between MTBF and the price of spares. The underlying computations for this trade-off are outlined in Section 6 of the Appendix.

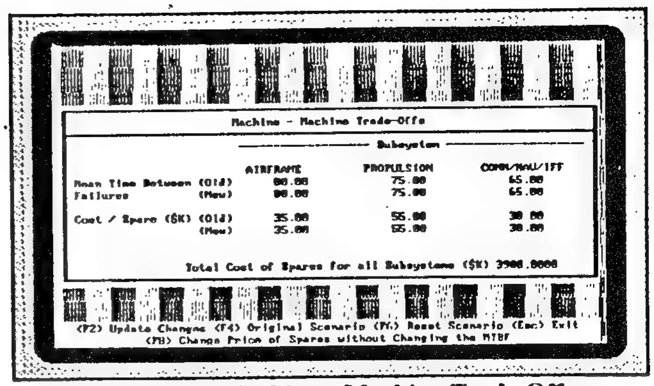

Figure 12. Machine - Machine Trade-Offs

2.5.2 Man - Machine Trade-Offs

Selecting this option allows the user to perform trade-offs between MPT and hardware resources. There are two options available on this menu branch. In the first the user can perform trade-offs between MTBF and the required workload of flightline level maintainers. In the second, the user can perform trade-offs between Base Level maintainer workload and the number of spare LRUs.

MTBF - Flightline Workload

Selecting the MTBF - Flightline Workload option lets the user see how the flightline level workload varies with MTBF. The SYSMOD Demo screen for this trade-off is shown in Figure 13. Changing the reliability of a subsystem has an inverse effect on the number of maintainers required, i.e. an increase in reliability results in a requirement for fewer maintainers required. Changing the reliability of one subsystem affects every AFS that is assigned a task for that subsystem. The analytical foundations for this trade-off screen are explained in Section 7 of the Appendix. Enter a new value for the MTBF and press <F2> to see the changes

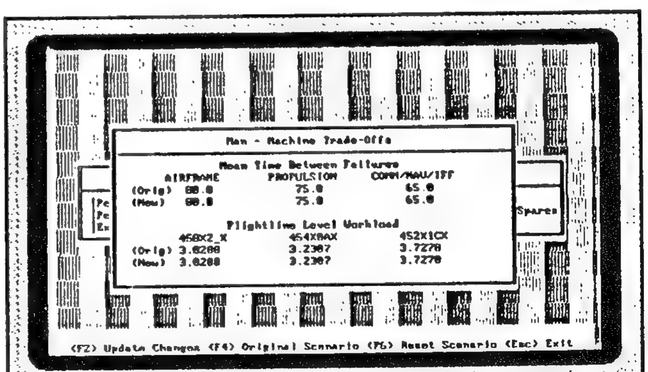

Figure 13. MTBF - Flightline Workload Trade-Offs

in the flightline level workload. Press <F4> to return to the original numbers, or press <F6> to re-run the simulation based upon the new values for the MTBF.

Base Level Workload - Number of Spares

Selecting the Base Level Workload - Number of Spares option lets the user change the number of base level maintainers to see the effect on the number of LRUs required to meet the demand for spare LRUs. Figure 14 shows the SYSMOD Demo screen for this trade-off. Enter a new number for base level maintainers and press <F2> to obtain the new requirement for spare LRUs. Press <F4> to return all of the values to their original state. Note that the level of spares that initially appears on this trade-off screen is the minimum number of spare LRUs required to meet the demands set by the user input sortie rate. The number of spare LRUs required by the model falls between an upper and lower bound. The lower bound occurs when there are no shortages in base level maintainers. Note that this number is probably not zero because of the way the maintenance network is set up. There will be a certain percentage of spares that cannot be fixed and must be thrown away. This establishes the minimum number of spare LRUs required; any fewer would cause a loss of sortie generation potential. There is also an upper bound on required spare LRUs. This level occurs when there are no base level maintainers to handle that subsystem's base level tasks or when base level maintenance was not selected in the input screens. This number represents the upper bound on spare LRUs required to meet the demand for spare LRUs without a loss of sortie generation potential.

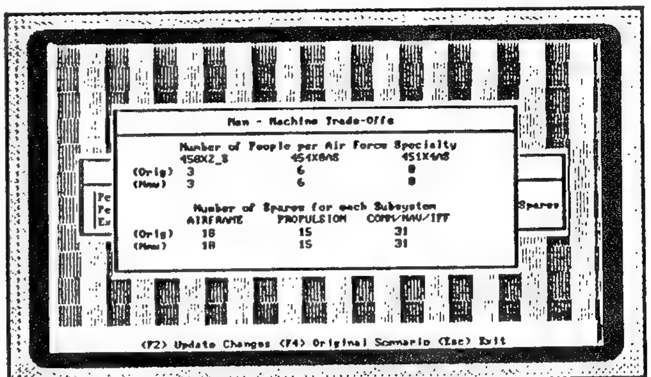

Figure 14. Base Workload - No. of Spares Trade-Offs

The number of base level maintainers required falls in a range from zero to some upper bound. The upper bound on base level maintainers is the number of base level maintainers required to meet demand while keeping the monthly spare LRUs purchase to its lower bound. The initial numbers on this trade-off screen show the numbers of base level maintainers at their upper bounds and the numbers of spare LRUs at their lower bounds. Therefore, raising the number of base level maintainers from the initial value on this screen will have no effect on the requirement for spare LRUs. Similarly, reducing the number of spare LRUs will have no effect on the requirement for base level maintainers; however, it will reduce the sortie generation potential for the scenario.

Further discussion of the relationship between spare LRUs and base level maintainers can be found in Section 9 of the Appendix.

2.5.3 Man - Man Trade-Offs

Selecting this option allows the user to conduct trade-off analyses among MPT resources. There are two options available on this menu branch. The first option allows the user to reallocate the specific tasks to different AFSs. The second option lets the user conduct trade-offs between the level of experience of the maintainers and the Mean Time To Repair (MTTR) for a particular task. Flightline and base level tasks for the two options are considered on separate screens.

Reallocate Tasks to AFSs

Since separate screens are used to reallocate MPT resources for flightline and base level maintainers, select the maintenance level you would like to change. The following instructions apply to both the flightline and the base-level branches. Task Reallocation trade-offs allow the user to change the AFS assigned to a specific task. Figure 15 shows this trade-off screen for the flightline level. The tasks for each subsystem are listed as rows on the left half of the screen. The columns are the three AFS's. The user places an "X" in the appropriate space to select a particular AFS for a specific task. Since only one AFS is allowed to participate in the workcrew of any one task, selecting an "X" in one field automatically places an "O" (denoting that the AFS has no part in that task) in all other AFSs for that task. Press <F2> to see how this reallocation changes the relevant statistics, i.e. total manning and training and wage costs, both in thousands of dollars. Press <F4> to return to the original values that existed at the end of the last simulation. Press <F6> to re-run the simulation with the new data. Sections 2 and 3 of the Appendix explain the analytical process of finding the workload for each task and then computing the workload for each AFS. Reallocating a task to a different AFS also has implications for training times. Because the training time for tasks can be affected by training required for other tasks, total training time for an AFS may not be simply the sum of the training times for its tasks. The training cost fields on this screen show whether the effects of the reallocation have a positive or negative

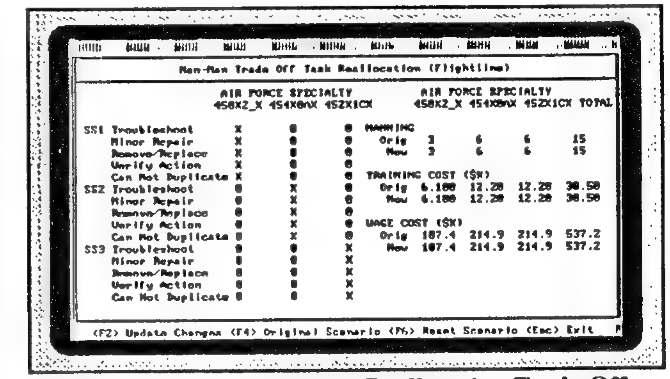

Figure 15. MPT Resource Reallocation Trade-Offs

effect on training costs. The formulation of training times for AFSs is discussed in Section 5 of the Appendix.

Perform Trade-Offs with Experience Level and Task Time

Trade-offs between Experience Level and Task Time allow the user to change the experience level (i.e. the skill level or grade) of the maintainers in the workcrew for a given task and see the effects on the Mean Time To Repair (MTTR) for that task. Figure 16 shows the screen for this trade-off. Each workcrew has one to three maintainers, and each member of the crew may have a different experience level. SYSMOD assumes that a maintainer with more training and experience can perform a given task faster than one with less training and experience. The Man - Man trade-off allows the user to examine the interaction of experience level and task time. The analytical relationships are explained in detail in Section 10 of the Appendix.

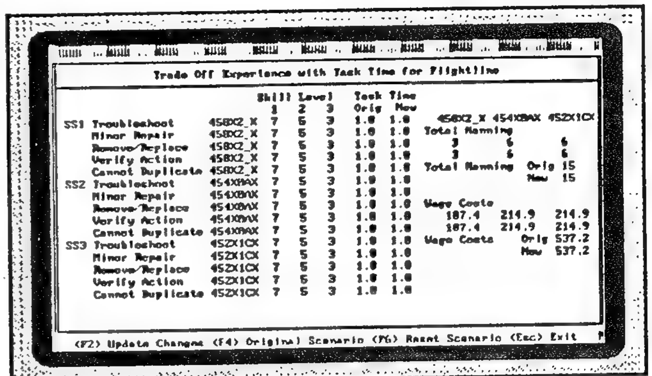

Figure 16. Experience - Task Time Trade-Offs

The following instructions apply to both the flightline and base level screens. Specific tasks for each subsystem are listed as rows on the left-hand side of the screen. The skill levels or grades for each maintainer (1, 2 and 3) are given as columns. Each task can have a workcrew of up to three maintainers, each with his or her own skill level or grade. If only one or two maintainers are needed, the other columns are set to zero. Relevant data for each AFS, such as total manning and wage costs, are given along the right side. Note that as maintainer experience and training increase, maintainer wages increase though total manning required may decrease. The total manning fields on the right of the screen show the total manning for each AFS before the changes (top row) and after (bottom row). Similarly, the total wage costs for each AFS (and the sum) are shown before changes (top row) and after (bottom row).

To make changes in the model, press <F2> to see how changes in experience level affect the relevant statistics. Press <F4> to return to the original data used in the latest simulation run. Press <F6> to re-run the simulation using the new data. Rerunning the simulation will reset the original values to the new values found by executing the trade-off.

2.6 SAVE SCENARIO TO A FILE

Selecting this option allows the user to save the scenario data into an ASCII file. There is no need to enter an extension for the filename since the extension ".smd" is added automatically to any filename that you enter. Make sure that the filename entered has fewer than eight characters. If an extension is added to the filename, that extension will be dropped in favor of the ".smd" extension. The "insert" key can be pressed to see a listing of previously stored data sets if you wish to save your simulation data to an existing file. In the current version of the Demo, saving data to an existing file can cause problems with the SYSMOD Demo menus. We recommend exiting from SYSMOD after saving a scenario and reentering the Demo to continue processing.

2.7 CONCLUSION

It is important for the user to note that this demonstration software is a first attempt to illustrate the operation of SYSMOD during Concept Exploration. Thus only a few systems are represented and functional relationships are modeled so that changes in inputs produce changes in outputs that are in the appropriate direction. As SYSMOD is further developed, this demonstration software can be improved and expanded to include a wider variety of trade-off models to assist the analyst as well as to elicit feedback from the Air Force user community.

APPENDIX

SYSMOD DEMONSTRATION MODEL USER'S MANUAL

The functions used in the SYSMOD Demo are designed to respond in the right direction to changes in inputs. Because the functions are simplified to yield results quickly, the user should not rely on the numerical results produced by the functions.

1. CONSTRAINED SORTIE RATE

The constrained sortie rate is the total number of sorties per day allowed by the particular combination of Manpower Personnel Training (MPT) resources and spares. This value is derived by taking the Total System Sorties (TSS) (defined below) and subtracting sorties lost due to one or more of the following factors: normal aircraft maintenance downtime, lack of manpower, or lack of spare parts. Note that the constrained sortie rate can be higher than the desired sortie rate.

Finding the constrained sortie rate is an involved process. First, one needs to find the total number of sorties that can be flown under ideal conditions, hereafter referred to as Total System Sorties. Ideal conditions assume zero downtime for maintenance repair, sufficient manpower and sufficient spare parts. Therefore

$$TSS = \Psi \alpha \tag{1}$$

where TSS, Total System Sorties, is the wing's maximum possible sorties per day; Ψ is the maximum number of sorties that can be flown per day per aircraft given input on the length of the sorties; and α is the number of aircraft in the wing, assumed to be 72 in the SYSMOD Demo. The required system sorties per day is given by

$$\sigma = \sum_{i=1}^{n} \nu_i \eta_i \tag{2}$$

where n is the number of types of missions flown, υ_i is the number of missions of type i flown during one day, and η_i is the number of sorties (aircraft) required to perform mission i.

Finding the value for Ψ requires some computation from the actual input data received from the SYSMOD Demo. Mission data are entered into the SYSMOD Demo using three parameters: the number of missions that are flown in one day, the number of aircraft required for that mission, and the length (in hours) of the sorties being flown on that mission. The SYSMOD Demo allows for up to five mission types. Note that the value of Ψ can have either sorties or flying hours as its unit of measurement. Throughout this appendix, the discussion will use the number of sorties rather than number of flying hours as the unit of measurement for Ψ. Using flying hours would change several formulas slightly.

The value of the average length of a sortie is given by

$$\Gamma=\frac{\sum_{i=1}^{n}\nu_i\eta_i\lambda_i}{\sigma} \qquad (3)$$

where Γ is the average length of the sorties in hours, n is the number of types of missions being flown, ν_i is the number of missions of type i flown during one day, η_i is the number of sorties (aircraft) required to perform mission type i, λ_i is the length in hours of the sorties for mission type i, and σ is the required system sorties per day. This formula is simply the weighted average of the mission lengths by the number of sorties flown of that mission. The maximum possible number of sorties per aircraft per day is

$$\Psi=\frac{24}{\Gamma} \qquad (4)$$

Sorties Lost to Downtime

Once these parameters have been formulated, the total sortie loss due to maintenance downtime must be calculated. Calculating this downtime requires several steps.

When an aircraft subsystem fails, that aircraft is grounded and fixed before it can fly again. The time required to perform the various maintenance tasks constitutes lost sorties that the aircraft could have flown had it not been in the shop. The expected value formula for this downtime for any given subsystem is

$$DT_i=MTTR_{i1}+(X_iMTTR_{i2})+(Y_iMTTR_{i3})+(1-X_i-Y_i)MTTR_{i4}+MTTR_{i5} \qquad (5)$$

where DT_i is the expected value of the downtime in hours for subsystem i, $MTTR_{ij}$ is the Mean Time To Repair in hours for subsystem i and flightline task j (Task 1 is Troubleshoot, Task 2 is Remove and Replace, Task 3 is Minor Repair, Task 4 is Cannot Duplicate, and Task 5 is Verify), X_i is the probability Line Replaceable Units (LRUs) are removed and replaced after the troubleshoot operation, Y_i is the probability LRUs are repaired on the flightline, and $(1-X_i-Y_i)$ is the probability that no failure was found.

The expected value of the downtime of the weapon system can be expressed as a function of the expected values of its component subsystems. This formula is
where WSDT is the expected mean time to repair for any given malfunction of the weapon system, DT_i is the expected value of the downtime for subsystem i, and $1/MTBF_i$ is the per sortie probability that subsystem i fails.

$$WSDT=\frac{\left(\frac{DT_1}{MTBF_1}+\frac{DT_2}{MTBF_2}+\frac{DT_3}{MTBF_3}\right)}{\left(\frac{1}{MTBF_1}+\frac{1}{MTBF_2}+\frac{1}{MTBF_3}\right)} \tag{6}$$

This formula may look intimidating but it is actually only a weighted average of probabilities and downtimes. It is logical that the expected value of the aircraft downtime reflects the average downtimes of the component subsystems to the degree that those respective downtimes occur. The above formula weights the subsystem downtime (DT_i) with the probability that the downtime occurs ($1/MTBF_i$).

Similarly, the expected value of the mean time between failures (MTBFs) of the weapon system expressed in terms of its component subsystem MTBFs is

$$SMTBF=\frac{1}{\left(1-\left(1-\frac{1}{MTBF_1}\right)\left(1-\frac{1}{MTBF_2}\right)\left(1-\frac{1}{MTBF_3}\right)\right)} \tag{7}$$

where SMTBF is the expected value of the MTBF of any component of the weapon system and $MTBF_i$ is the MTBF of subsystem i. This formula is a restatement of the law of probability which states that the probability that the entire weapon system fails equals the probability that any subsystem of that weapon system fails. Further, the probability that any subsystem of the weapon system fails is also equal to one minus the probability that all of the subsystems function properly. Therefore

$$P(WS^{failure})=1-\prod_{i=1}^{n} P(SS_i^{success}) \tag{8}$$

where $P(WS^{failure})$ is the probability that the weapon system fails, $P(SS_i^{success})$ is the probability that subsystem i does not fail, i denotes the subsystem, and n is the number of subsystems. Since there are only three representative subsystems in the Demo, this formula reduces to a much simpler one. Denoting P(A) as the probability that no failure will occur (success) for subsystem one and P(B) and P(C) likewise for subsystems 2 and 3, respectively, we have

$$P(WS^{failure})=1-P(A)P(B)P(C) \tag{9}$$

In terms of $MTBF_i$, P(A), P(B) and P(C) can be stated as

$$P(A)=1-\frac{1}{MTBF_1} \tag{10}$$

$$P(B)=1-\frac{1}{MTBF_2} \tag{11}$$

$$P(C)=1-\frac{1}{MTBF_3} \tag{12}$$

Given the probability of success is one minus the probability of failure and the probability of failure is the reciprocal of the MTBF, we find the formula given in equation (5).

Using the values for the weapon system failure rate (equation 5) and the weapon system downtime (equation 4), we can derive the loss of sortie generation potential due to maintenance downtime. Each time an aircraft fails, it remains on the flightline for the duration of the downtime for that aircraft. The expected number of sorties that it will miss is based upon the expected length of this downtime and the expected length of a sortie. The expected number of sorties lost for any one malfunction is given by

$$\beta=\frac{WSDT}{\Gamma} \tag{13}$$

where β is the number of sorties lost due to one breakdown, WSDT is the average downtime for maintenance, and Γ is the average length of a sortie. For every breakdown we can expect that β sorties will be lost and must be subtracted from the sortie generation potential. Now we need to find the number of times that this downtime occurs. This is simply a function of the expected failure rate of the various components of the weapon system. The formula for the total number of sorties lost due to maintenance downtime is

$$LS_{MD}=\frac{\beta\sigma}{SMTBF} \tag{14}$$

where LS_{MD} is the sorties lost due to maintenance downtime, β is the number of sorties lost due to one breakdown. σ is the required number of system sorties (computed above from input mission data), and SMTBF is the expected value of the MTBF for the weapon system (computed above). This is an approximation of lost sorties due to maintenance downtime. In reality, this relationship is not strictly linear as it would appear in equations 13 and 14. The more sorties lost due to aircraft downtime, the fewer sorties that can be performed. This means that the value of β trails off at

greater MTBFs as downtime reduces available flying hours per day below the number required for TSS. We have not illustrated this process here but have modeled the phenomenon in the SYSMOD Demo using a recursive procedure.

Sorties Lost to Manpower Shortages

Sections 2 and 3 of this Appendix examine the numbers of maintainers that are required for each task and Air Force Specialty (AFS). A shortage of flightline maintainers would adversely affect the sortie generation potential. A shortage of base level maintainers may also have an effect on sortie generation potential. A shortage of base level maintainers causes an increase in the number of spare LRUs required. If this requirement for spares is not met, then sortie generation potential suffers. Thus, a shortage of base level maintainers causes a shortage of spares that causes a decrease in sortie generation. The effects of spare deficiencies on sortie generation potential is discussed later in this section. Hereafter in this discussion of the effects of manpower shortages on the sortie generation rate, references to AFSs will mean flightline AFSs only.

The effects on the sortie rate of a shortage of people in an AFS are not easily derived since one AFS can work on several tasks from several subsystems. What must be done first is to determine which AFSs have shortages and where those shortages limit the rate at which an aircraft in need of repair moves through the repair system. Calculating the effect on sortie rate is then a matter of identifying the task probability and repair time combination that limits the number of repairs the most. The formula for calculating sorties lost due to manpower shortages is

$$LS_{MS_i}=\frac{\sigma}{\alpha}\underset{j}{MAX}\left[\frac{\delta_{ijk}SHRT_{ijk}P_{ij}8(1-\theta)}{MTTR_{ij}}\right] \tag{15}$$

where σ/α is the wing's required sorties per day; δ_{ijk} is one when task j on subsystem i is assigned to AFS k and zero, otherwise; SHRT is the number of crews AFS k is short per day for task j on subsystem i; P_{ij} is the probability that task j is needed when subsystem i fails (See Figure A-1.); $8(1-\theta_k)$ is the hours of an eight hour shift that a crew from AFS k is available to perform maintenance; $MTTR_{ij}$ is the mean time to accomplish task j on subsystem i.

The total number of sorties lost per day due to manpower shortages is given by the sum of the losses due to each subsystem.

$$LS_{MS}=\sum_i LS_{MS_i} \tag{16}$$

It is reasonable to conclude that the effect of manpower shortages on sortie generation potential decreases as the manpower shortages increase. That is, the 14th missing maintainer does not contribute as much to the lost of sortie generation potential as the first missing maintainer does. This is because the effect of that maintainer on the loss of sortie generation potential is proportional to the sortie rate that can be achieved. As we lose maintainers, the sortie rate decreases. The sorties lost due to manpower shortages, LS_{MS}, are modeled in SYSMOD using a recursive procedure that tracks this marginal effect for all of the mission AFSs.

Sorties Lost to Spares Shortages

Subsystem failures generate a requirement for spare LRUs. Should this spares requirement not be met, a loss in sortie generation potential results. This is the third factor that can decrease the constrained sortie rate and hence the performance of the system as a whole. If there is a shortage in spares of any subsystem, this causes the aircraft to be down. The formula quantifying lost sorties due to spares shortages is

$$LS_{SD}=\frac{\sigma}{\alpha}MAX(RS_1-S_1,RS_2-S_2,RS_3-S_3,0) \qquad (17)$$

where LS_{SD} is the lost sorties due to spares deficiencies, σ/α is the required sorties per aircraft per day, S_i is the number of spares available for subsystem i, and RS_i is the number of spares required for subsystem i (defined in Section 8).

Thus the constrained sortie rate can be stated as

$$CS=TSS-LS_{MD}-LS_{MS}-LS_{SD} \qquad (18)$$

where CS is the constrained sortie rate, TSS is the total system sorties, LS_{MD} is the sorties lost due to maintenance downtime, LS_{MS} is the sorties lost due to manpower shortages, and LS_{SD} is the sorties lost due to spare deficiencies.

2. WORKLOAD PER TASK

This term refers to the number of maintainers that are required to perform any particular task. Flightline tasks are Troubleshoot, Remove and Replace, Cannot Duplicate, Minor Repair and Verify. Base level tasks consist of Troubleshoot and Major Repair. The manning required to perform a particular task is defined by

$$TM_{ij}=\frac{N_{ij}MTTR_{ij}P_{ij}\sigma}{8(1-\theta_k)MTBF_i} \qquad (19)$$

where TM_{ij} is the Total Manning for task j on subsystem i; N_{ij} is the number of maintainers for subsystem i and task j; $MTTR_{ij}$ is the expected time to complete task j on subsystem i, P_{ij} is the probability that task j will be required for a failed subsystem i, σ is the wing's required sorties per day; $8(1-\theta_k)$ is the number of hours each day that members of AFS k are available to perform maintenance; and $MTBF_i$ is the mean number of sorties between failures for subsystem i.

To define the values of P_{ij}, please refer to Figures A-1 and A-2 in Section 8 of this Appendix. These figures show the maintenance network for both the flightline level and the base level. Let's first look at the flightline level and define P_{ij} for each task.

Troubleshoot (Task 1): The value of P_{i1} equals 1 since all tasks must go through the troubleshoot operation to determine the cause of malfunction. Remove/Replace (Task 2): The value of P_{i2} equals the value assigned to X_i. Minor Repair (Task 3): The value of P_{i3} equals the value assigned to Y_i. Cannot Duplicate (Task 4): The value of P_{i4} equals $(1-X_i-Y_i)$. Verify (Task 5): The value of P_{i5} equals 1 since every aircraft must go through the Verify procedure in order to be released to fly sorties.

For base level repair refer to Figure A-2 but remember that in order for a defective LRU to get to the base level, it first must go through the Remove/Replace operation on the flightline. That means that any probabilities on the base level must be multiplied by X_i, the probability of an LRU being removed and replaced on the flightline. The values for P_{ij} for base level maintenance follow: Troubleshoot (Task 1): $P_{i1} = X_i$; Major Repair (Task 2): $P_{i2} = X_iZ_i$.

3. MANNING FOR AFS

The total manning for each AFS is computed by a simple expected value formula. In the SYSMOD Demo, each of the three subsystems has five flightline and two base level tasks. Each of these tasks requires a workcrew of one to three maintainers. Each task has an assigned AFS; the first three AFSs are restricted to flightline work, while the final three AFSs are restricted to base level work. Maintainers are divided within their AFSs into skill levels or grades; however, for the discussion in this manual, skill levels are used.

The total manning for an AFS depends upon how many tasks are assigned to that AFS. Since an AFS can be assigned to any number of tasks, the total manning for any given AFS is

$$AFSM_k = \sum_{i=1}^{n} \sum_{j=1}^{m} \delta_{ijk} TM_{ij} \tag{20}$$

where $AFSM_k$ is the manning for AFS k; δ_{ijk} is 1 if task j for subsystem i is assigned to AFS k and 0 otherwise; and TM_{ij} is defined in Equation 17.

Simply stated, the total manning for any AFS k is the sum of the manning for all of the tasks (explained in Section 2 of the Appendix) assigned to that AFS.

4. BASE OPERATING SUPPORT MANNING

This term refers to the total manpower that is required for Base Operating Support (BOS). This value is set at 14% of the total manpower requirements for all maintenance related AFSs. This 14% factor is an average factor used by the Air Force Management Engineering Agency (AFMEA).

5. TRAINING LENGTH

The SYSMOD Demo simplifies the training process for aircraft maintainers by dividing training into two categories: classroom (technical school) and Field Training Detachment (FTD). A maintainer assigned to each task for each subsystem requires certain amounts of training in these two settings to adequately perform that task. Each subsystem task for both flightline and base level has four different sets of training times, one for each skill level (3, 5, 7, and 9). When an AFS is assigned to two or more tasks, the AFS requires training in all of these tasks. The SYSMOD Demo assumes that some of the training for different tasks will be repetitive and thus the total training time will be less than the sum of the training times for each task assigned to the AFS. The formula that the SYSMOD Demo uses to estimate the amount of training time required for an AFS is

$$AFSTr_k = .8\tau_k^{max} + .2\sum_{i=1}^{n} \sum_{j=1}^{m} \delta_{ijk} \tau_{ij} \tag{21}$$

where $AFSTr_k$ is the amount of training required for AFS k; δ_{ijk} is one if task j on subsystem i is assigned to AFS k, and zero otherwise; τ_{ij} is the training time required for task j on subsystem i; and τ_k^{max} is the training time that is the longest of all of the tasks allocated to AFS k.

The above formula is applied to both classroom and FTD training. Essentially, this formula says that in order to adequately train an AFS for multiple tasks, the total training time will equal the

longest training time of those tasks plus 20 percent of the remaining training times. Reminder: This formula is an approximation for purposes of the Demo.

6. COST OF SPARES AS A FUNCTION OF MEAN TIME BETWEEN FAILURES

For each subsystem there is an associated MTBF. Improving the MTBF of a subsystem requires additional resources for the research, development, and production efforts that go into making any product more reliable. These additional resources increase the cost of the spare LRUs.

In the SYSMOD Demo, the relationship between increased reliability (greater MTBF) and cost of spares is assumed to be proportional. In other words, an increase in MTBF of *X* percent increases the cost of any spare LRUs purchased by *X* percent.

For example, assume a propulsion system has a MTBF of 120 sorties and the cost of an LRU is $240,000. If the user requests that the MTBF be increased to 150 sorties, the model changes the price of one spare for this propulsion system to $300,000 (i.e. a 25% increase in both MTBF and the price). Note: These automatic changes only occur in the trade-off section of the model. During initial parameter input, the MTBF and the cost of spares can be set without regard to this proportional relationship. Also, if during a trade-off the user feels that the relationship does not hold, there is an override key that can be used to set the MTBF and the cost of spares independently. The instructions for this are detailed in Section 2.5.1 of the user manual.

7. FLIGHTLINE WORKLOAD AS A FUNCTION OF MEAN TIME BETWEEN FAILURES

Changing the MTBF of any subsystem will affect the workload of flightline maintainers who repair that subsystem. Sometimes, different AFSs work on the same subsystem, so that a change in the MTBF of one subsystem causes changes in the manpower requirements in more than one AFS.

To examine the effect that MTBF has on flightline workload, we must look at the relationship between the two variables. In this case, flightline workload is a function of the MTBF of the subsystem. The expected value formula relating these two variables, as used in the SYSMOD Demo software, is

$$W_k = \sum_{i=1}^{n} \sum_{j=1}^{m} \delta_{ijk} (\sigma N_{ij} MTTR_{ij}) / MTBF_i \tag{22}$$

where W_k is the flightline workload for AFS k (measured in hours of maintenance); δ_{ijk} is one if task j of subsystem i is assigned to AFS k, and zero otherwise; σ is the number of sorties flown by the wing

per day; N_{ij} is the number of maintainers in a workcrew for subsystem i and task j; $MTTR_{ij}$ is the MTTR for task j on subsystem i (measured in hours); and $MTBF_i$ is the MTBF for subsystem i (measured in sorties[1]).

From this formula we can see that as the MTBF of a subsystem increases, the number of maintainers required for this subsystem decreases. In order to better show how this relationship works, a notional example is provided:

Consider the case of determining the flightline level workload for AFS 1. AFS 1 is assigned to work on Subsystem 1, Task 1 (Airframe, Troubleshoot) and Subsystem 2, Task 1 (Propulsion, Troubleshoot). The parameters are defined as follows:

W_1	= Flightline workload for AFS 1 (maintainer-hours/day)
δ_{111}	= 1
δ_{211}	= 1
σ	= 360 sorties/day
N_{11}	= 3 maintainers
N_{21}	= 2 maintainers
$MTTR_{11}$	= 1.5 hours/failure
$MTTR_{21}$	= 2.5 hours/failure
$MTBF_1$	= 50 sorties/failure
$MTBF_2$	= 30 sorties/failure

The flightline workload for this case is:

$$W_1=\sum_{i=1}^{2}\sum_{j=1}^{1} 1(360*N_{ij}*MTTR_{ij})/MTBF_i \tag{23}$$

which is:

$$W_1=(360*3*1.5)/50+(360*2*2.5)/30=32.4+60 \tag{24}$$

$$= 92.4 \text{ maintainer-hours/day}$$

---

[1] This formula applies when sortie rate is used as the flight frequency parameter. The formula differs slightly when flying hours are used.

Using an overhead fraction of .22 and the eight hour workday assumed in the Demo, 92.4/(8(1-.22)) = 14.8 or 15 maintainers are required to handle the workload for AFS 1.

The relationship between flightline workload and MTBF is not strictly linear when considered in the broader sense. In other words, since different AFSs work on different tasks for any given subsystem, the relationship is difficult to approximate. The model re-calculates the flightline workloads given the new MTBF(s) in the trade-off screen.

8. MINIMUM NUMBER OF SPARES REQUIRED

The SYSMOD Demo allows for two levels of maintenance: the flightline and the base level. For each of these levels of maintenance, there is a maintenance network that defines the path that a particular LRU takes after it has failed. The flightline subsystem looks like the graph depicted in Figure A-1.

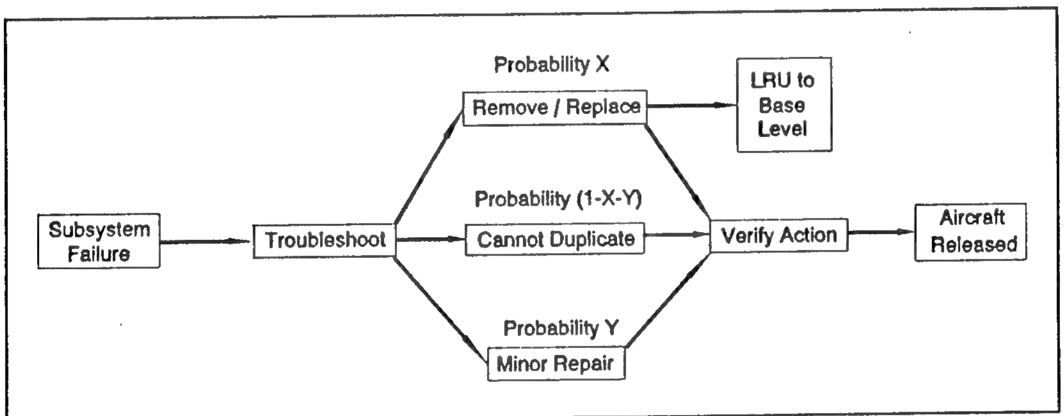

Figure A-1. Flightline Level Maintenance Network

Following a failed LRU though the network, we find that the LRU goes immediately to Troubleshoot. Once this task is completed, the LRU goes to one of three options with a given probability. With probability X, the LRU is Removed and Replaced with a spare LRU, and the defective LRU is sent to the base level for further diagnosis and repair. With probability (1-X-Y), the tests show nothing wrong with the LRU. With probability Y, the LRU requires a Minor Repair which is done right on the flightline. From all three branches, the next step is to Verify the performance of the LRU on the aircraft before the aircraft is released from maintenance. The branch that we are most interested in at this point is the branch that sends the defective LRU to the Base Level for further action. Once the LRU is sent to this branch, it continues through the network shown in Figure A-2.

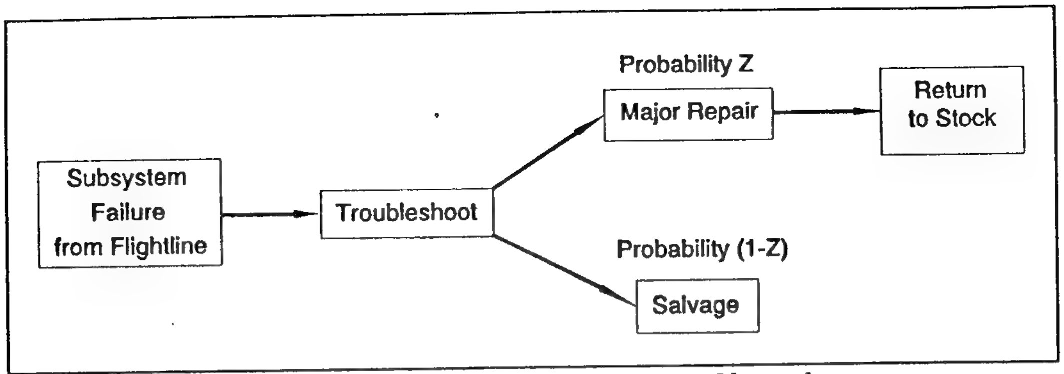

Figure A-2. Base Level Maintenance Network

Once at the base level, the LRU goes immediately to the base level Troubleshoot operation. Upon completion of this step, the LRU goes to one of two options. With probability Z, the LRU undergoes a Major Repair and then is returned to stock. With probability (1-Z), the LRU is irreparable and is sent to salvage. This final branch is what we are most interested in to explain the concept of minimum number of spares required.

With a non-zero probability of LRUs being lost to salvage, we have introduced a sink for spares for every subsystem. We must introduce a corresponding source to refresh the supply of spares lest that supply dwindle to zero and cause a loss of sortie generation potential. In other words, one must purchase additional LRUs on a daily basis to replenish the loss to the inventory of spare LRUs caused when LRU's are salvaged, not repaired. Note that this assumes steady state equilibrium with respect to spares.

The minimum number of spares to be purchased is governed by the relationship between several parameters. The value of the minimum expected spare purchase per day can be found using

$$RS_i = \frac{(X_i(1-Z_i)\sigma)}{MTBF_i} \tag{25}$$

where RS_i is the number of spares required per day for subsystem i, X_i is the probability that the LRU is removed and replaced after the flightline troubleshoot (as illustrated in Figure A-1), $(1-Z_i)$ is the probability that the LRU is sent to salvage after the base level troubleshoot (as illustrated in Figure A-2), σ is the wing's required sorties per day, and $MTBF_i$ is the MTBF for subsystem i (measured in sorties).

This formula can be derived by taking the total number of subsystem failures ($\sigma/MTBF_i$) and following those LRUs though the two maintenance networks to get the number of failed LRUs that eventually find their way to salvage.

The minimum monthly spares purchase is zero only in certain circumstances: 1) there are no sorties being flown, 2) parts are always repaired on the flightline (i.e. X equals zero), or 3) no LRUs are sent to salvage (i.e. Z equals one).

9. NUMBER OF SPARES AS A FUNCTION OF NUMBER OF BASE LEVEL MAINTAINERS

Base level maintainers perform troubleshooting and major repairs on LRUs that cannot be fixed on the flightline. Essentially, base level maintainers take LRUs that would otherwise be unusable and make them usable again. Thus the effect of a shortage of base level maintainers is a loss of spares that come back into the system. In order to make up this deficiency, additional spares must be purchased.

As discussed in the previous section, there is a minimum level of spares that must be purchased in order to maintain equilibrium for sortie generation potential. The lower bound occurs when there are no shortages of base level maintainers to repair LRUs and return them to stock. There is also an upper bound over which additional spares do not contribute to a greater number of sorties; they are wasted. This level of spares occurs when the number of base level maintainers drops to zero (or when the option for base level maintenance is not selected in the SYSMOD input screens).

Similarly, there is an effective range for base level maintainers. The lower bound is simply zero. The upper bound represents the number of maintainers required to meet demand and keep the monthly spares purchase to its lower bound. The initial numbers on the Man-Machine trade-off screen show the numbers of base level maintainers at their upper bounds and the numbers of spares at their lower bounds.

The relationship between base level maintainers and the number of spares required can be derived from an equation relating the rate at which LRUs fail and the rate at which new or repaired LRUs are sent to the flightline for use. For steady state equilibrium, the number of spares sent to the base due to malfunction must equal the number the spares sent to the flightline via either repair from base level maintenance or from additional spares purchases. Therefore, to maintain steady state equilibrium

$$S_i(t)=L_i(t) \tag{26}$$

where $S_i(t)$ is the flow of new or repaired spare LRUs for subsystem i to the flightline over time t and $L_i(t)$ is the flow of failed LRUs for subsystem i to base level repair. We can formulate equations for each of the variables $L_i(t)$ and $S_i(t)$. For a time period of one day the expected number of units of subsystem i sent to base level for repair, L_i, is given by

$$L_i=\frac{X_i\sigma}{MTBF_i} \tag{27}$$

where X_i is the probability a failure is due to a malfunctioning LRU that must be sent to base level for repair, σ is wing's required sorties per day, and $MTBF_i$ is the Mean Time (sorties) Between Failures for subsystem i.

The number of LRUs generated during a day is a combination of those purchased and those repaired by base level maintainers

$$S_i=S_{i_p}+S_{i_r} \tag{28}$$

where the second subscript on S_i indicates units purchased (p) or repaired (r). To repair an LRU both the troubleshoot and the major repair tasks must be accomplished. Let us look at the capacity of base level maintainers for conducting the troubleshoot task (task 1, j=1):

$$C_{i1}=\frac{AFS_{k_{i1}}8(1-\theta_k)}{MTTR_{i1}} \tag{29}$$

and for conducting the major repair task (task 2, j=2):

$$C_{i2}=\frac{AFS_{k_{i2}}8(1-\theta_k)}{MTTR_{i2}} \tag{30}$$

where the second subscript on C indicates the task, $AFS_{k_{ij}}$ represents the total number of workcrews from AFS k that are assigned to task j on subsystem i over the day, $8(1-\theta_k)$ is the number of hours each crew of AFS k is available for performing maintenance each day, and $MTTR_{ij}$ is the expected time to accomplish task j on subsystem i.

The number of failed units of subsystem i that can be processed by the AFS responsible for troubleshooting is:

$$R_{i1}=\min(L_i,C_{i1}) \tag{31}$$

which is simply the minimum of the units that need troubleshooting and the capacity of maintainers to provide troubleshooting.

The number of units of subsystem i that can be processed by the AFS responsible for major repairs is:

$$R_{i2}=\min[Z_iR_{i1},C_{i2}] \tag{32}$$

which is the minimum of the units that reach the major repair task (see Figure A-2) and the capacity of maintainers to conducting major repairs. But this is the number of units of subsystem i repaired each day:

$$S_{i_r}=R_{i2} \tag{33}$$

Thus the number of spares for subsystem i that must be purchased each day to prevent a shortage of spares over the long run is given by

$$S_{i_p}=L_i-S_{i_r} \tag{34}$$

10. TASK TIME AS A FUNCTION OF EXPERIENCE

Each particular task is handled by a workcrew. The SYSMOD Demo allows workcrew sizes to vary from one to three maintainers. Each maintainer can have a different experience level, defined here as a skill level of 3, 5, 7, or 9 (or grade level 4, 5, 6, or 7). It is reasonable to assume that a maintainer with more training and experience can perform the same task faster than one who has less training and experience. The Man-Man Trade-offs allow for changing experience level (and hence salary) for faster or slower task times. This section will explain the methodology behind the quantification of this relationship.

In the input screens of the SYSMOD Demo, the user enters several parameters, among them the skill levels (or grades) of the members of all of the workcrews. The experience level - task time trade-off screen allows the user to change the skill levels (grades) of the flightline or base level workcrews to see how these changes affect: a) the performance time for that task b) the overall performance of the system and c) the wage costs of the maintainers. When the user replaces an airman of low skill level with one of higher skill level, the task time for that particular task goes down and vice versa. The SYSMOD Demo gives greater weight to experience changes in flightline and

base level troubleshoot tasks. It is reasoned that experience plays a greater role in troubleshooting than in other more straightforward tasks. The effect of changing the experience level of one maintainer in a troubleshooting workcrew is:

$$MTTR_{ij}^{new}=[(\frac{SL_k^{old}}{SL_k^{new}}-1)/\omega_{ij}+1]MTTR_{ij}^{old} \tag{35}$$

The effect of experience changes on other tasks is simply watered down according to

$$MTTR_{ij}^{new}=[(\frac{SL_k^{old}}{SL_k^{new}}-1)/(2\omega_{ij})+1]MTTR_{ij}^{old} \tag{36}$$

where SL_k^{new} is the new skill level for AFS k, SL_k^{old} is the old skill level for AFS k, and ω_{ij} is the size of the workcrew for subsystem i and task j.

The difference between these two formulas is that in non-troubleshooting tasks, the percentage multiplier has been cut in half (i.e. what would be a 10% increase in task time for troubleshoot, a multiplier of 1.10, would be a 5% increase in a non-troubleshooting task, a multiplier of 1.05).

11. GLOSSARY

TSS	Total System Sorties by all wing aircraft (sorties/day)(theoretical maximum)
Ψ	Maximum number of sorties per day by a single aircraft (sorties/day/aircraft)
α	Number of aircraft in the wing (72 in SYSMOD) (aircraft)
σ	Required system sorties (sorties/day)
n	Number of types of missions flown
υ_i	Number of missions of type i per day (Missions/day)
η_i	Number of aircraft required to perform mission type i. (Sorties/mission)
Γ	Average sortie length (hours/sortie)
λ_i	Length of sortie for mission number i (hours/sortie)
DT_i	Expected value of downtime for subsystem i (hours/failure)
$MTTR_{ij}$	Mean Time To Repair subsystem i, task j (hours/failure)
X_i	Probability that subsystem i LRUs are removed and replaced after the troubleshoot operation
Y_i	Probability that subsystem i LRUs are repaired on the flightline
$MTBF_i$	Mean Time Between Failures (sorties/failure)

$1/MTBF_i$	Probability that subsystem i fails
WSDT	Expected mean time to repair for the weapon system (hours/failure)
SMTBF	Expected value of the MTBF for the weapon system (sorties/failure)
β	Sorties lost due to one breakdown (sorties/failure)
LS_{MD}	Sorties lost due to maintenance downtime (Sorties/day)
LS_{MS}	Sorties lost due to manpower shortage (Sorties/day)
$(1-\theta_k)$	Fraction of time that a crew is available to perform maintenance
δ_{ijk}	1 if condition is met, and zero otherwise
$SHRT_{ijk}$	Number of crews AFS k is short for task j on subsystem i (Crews)
P_{ij}	Probability that task j must be performed when subsystem i fails
LS_{SD}	Sorties lost due to spares shortage (Sorties/day)
S_i	Number of spares available for subsystem i through purchase or repair (Spares)
RS_i	Number of spares required for subsystem i (Spares)
CS	Constrained sortie rate (Sorties/day)
TM_{ij}	Total manning for task j on subsystem i (Maintainers)
N_{ij}	Number of maintainers in a workcrew for subsystem i and task j (Maintainers)
$AFSM_k$	Manning for AFS k (Maintainers)
$AFSTr_k$	Training required for AFS k (Weeks)
τ_{ij}	Training time required for task j on subsystem i (Weeks)
τ^{max}_k	Training time that is the longest of all of the tasks allocated to AFS k.(Weeks)
W_k	Flightline workload for AFS k (maintainer-hours/day)
X_i	Probability that the LRU is removed and replaced after the flightline troubleshoot.
$(1-Z_i)$	Probability that the LRU is sent to salvage after the base level troubleshoot.
$S_i(t)$	Flow of new or repaired spare LRUs for subsystem i to the flightline over time t.
$L_i(t)$	Flow of failed LRUs for subsystem i to base level repair.
SL_k^{new}	New skill level for AFS k.
SL_k^{old}	Old skill level for AFS k.
ω_{ij}	Size of the workcrew for subsystem i and task j. (Maintainers)
S_{i_p}	Spares purchased for subsystem i. (Spares/day)
S_{i_r}	Spares generated through repair for subsystem i. (Spares/day)
$AFS_{k_{ij}}$	Workcrews per day assigned to task j, subsystem i from AFS k. (crews/day)
C_{ij}	Capacity of base level maintainers to perform task j on subsystem i. (Repairs/day)